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Scientometric Dimensions of Thorium Research in India

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ABSTRACT

This paper attempts to provide detailed quantitative analysis of Indian contributions on thorium in terms of publications output as per International Nuclear Information System database during 1970-2004. A total of 2399 papers were published by the Indian scientists in the field of thorium. There were only nine publications in 1970. Thereafter, a steady growth was observed except for the period 1983-1985. The highest papers (188) were published in the year 2000. USA with 8049 (28.05 per cent) and India with 2399 (8.30 per cent) publications were the top two countries who published work on thorium. Authorship and collaboration trend was towards multi-authored papers as 85.70 per cent of the papers were collaborative. There were 79 international collaborative papers. Bilateral collaboration accounted for 90.14 per cent of total collaborative papers. Bhabha Atomic Research Centre, Mumbai topped the list with 1251 authorships followed by Indira Gandhi Centre for Atomic Research, Kalpakkam with 168, Atomic Minerals Division, Hyderabad with 71, Utkal University, Bhubaneswar with 43 and Saha Institute of Nuclear Physics, Kolkata with 31 authorships, respectively. The journals most preferred by the scientists for publication of papers were: *Journal of the Indian Chemical Society* with 78 papers, followed by the *Indian Journal of Chemistry A* with 60 papers, *Bulletin of Radiation Protection* with 56 papers, *Journal of Radio Analytical and Nuclear Chemistry* with 54 papers, *Radiation Protection and Environment* with 37 papers, *Exploration and Research for Atomic Minerals* and *Journal of Geological Society of India* with 35 papers each. English was the most predominant language used by the scientists for communication. The high frequency keywords were: thorium (559), uranium (316), thorium oxides (269), India (257), solvent extraction (236), quantitative chemical analysis (221) and thorium 232 (202).

1. INTRODUCTION

It is strongly believed that energy is one of the most important components of the infrastructure responsible for accelerating the economic growth of a country. It is often said that energy breeds wealth and with increased energy consumption living conditions will improve[1-2]. Homi Jehangir Bhabha, the founder of Indian nuclear science, said that: "No energy is costlier than no energy". The strength of a country is measured in terms of its available energy resources and their efficient management.

Over the years, a lot of research has been conducted all over the world to find the alternative sources to tide over the energy problem as the earth's energy resources are being exhausted at a rapid rate. The nuclear industry has made tremendous strides in all sectors of science and technology since

the discovery of fission of Uranium by thermal neutrons by Otto Hahn and Fritz Straussman[3] in 1939, and a demonstration of self-sustaining controlled fission chain reaction by a team of scientists led by Enrico Fermi in 1942.

The first commercial nuclear power station started operation in the 1950s. Electricity now being produced the world over using nuclear energy is as much as it used to be from all sources combined in 1960. Civil nuclear power can now boast over 11,000 reactor years of experience and supplies 16 per cent of global needs. Today, 56 countries operate civilian nuclear research reactors, and 31 have around 440 commercial nuclear power reactors with a total installed capacity of over 3,60,000 MWe. This is more than three-times the total generating capacity of France or Germany from all sources. Some 30 power reactors, equivalent to 6 per cent of the existing capacity, are under construction, while about 35 power reactors, equivalent to 10 per cent of the present capacity, are firmly planned. Seventeen countries depend on nuclear power for at least a quarter of their electricity. France and Lithuania get around three-quarters of their power from nuclear energy, while Belgium, Bulgaria, Hungary, Slovakia, South Korea, Sweden, Switzerland, Slovenia, and Ukraine get one-third or more. Japan, Germany and Finland get more than a quarter of their power from nuclear energy, while the USA gets one-fifth[4]. India in comparison, currently generates most of its electricity by burning coal, some from hydro-electricity and only 3.7 per cent from nuclear power.

India with 1,30,000 MWe installed capacity is the fourth largest producer of electricity. The per capita electricity consumption in India is ≤ 600 kW hr per year (which is less than one-fourth of even the world's average value of 2500 kW hr per year) compared to the figure of about 10,000-12,000 kW hr per year for the developed countries. By 2050, India's population could rise to 1.5 billion, and its demand for electricity may increase up to 15-times more than what is being produced at present[5]. A lot of research is being carried out all over the world on thorium and its utilisation for energy production[6-13] as an alternative to uranium as thorium is available three-times more abundant in the earth's crust.

Different countries of the world have unequal natural, scientific, and geographical advantages. Hence, the conflicting parameters for consideration for forming the nuclear policy are varied. In other words, a particular reactor concept found most advantageous to one country may not prove economical to another[14]. The same is true in the case of India as the pattern of Indian resource profile is quite different from the rest of the world. India owns nearly third of the world's thorium reserves. To exploit this vast thorium reserves, India has adopted a wonderful road map; the famous three-stage nuclear power programme[15]. The first stage of the programme required building pressurised heavy water reactors powered by natural uranium that yields plutonium as a byproduct. In the second stage, the sufficient plutonium extracted from the spent cores would be used as a fuel in fast-neutron reactors, which can irradiate thorium and produce U 233 as a byproduct. In the third stage, advanced heavy water reactors will burn a mixture of U 233 and thorium, generating most of the power from thorium[16-17].

After completion of the third stage, breeders are destined to generate 500 MWe power for 350 years. Work on a 500 MWe prototype fast breeder reactor (PFBR) has already begun, and is expected to be commissioned by 2010[18]. To realise this three-stage nuclear power programme a lot of research and development activity has been going on in India on thorium.

Research publications are clearly one of the quantitative measures for the basic research activity in a country. It must be added, however, that what excites the common man as well as the scientific community, are the peaks of scientific and technological achievement, not just the statistics on publications. Publication and citation-counting techniques have been used for the assessment of scientific activity on thorium for at least fifty years. During the half-century of this

activity the main thrust of interest seems to flow along two connected but parallel paths: the bibliometric path of publication and citation counts as tools for the librarian, and an evaluative path using the same tools to illuminate the mosaic of scientific activity[19].

There are also other kinds of research and technology development oriented, industry oriented, country specific, etc., progress in the field of thorium. The actual research and development on thorium, therefore, cannot be obviously measured by counting the number of publications[20]. Kademani and Vijai Kumar[21-22] have given a bird's eye view of the bibliometric and scientometric techniques used to study various quantitative and qualitative aspects of the scientific endeavours.

Many scientometric studies have appeared in the literature to focus on the performance of science in various domains[23-31]. Kademani, et al[32] have carried out a quantitative study on the growth and development of world literature on thorium in terms of publication output as per Science Citation Index (1982-2004). The study showed a similar trend of collaboration towards multi-authored papers (89.66 per cent), and USA as the top research paper producing country with 1000 authorships (21.11 per cent) followed by India with 498 authorships (10.51 per cent). The study also revealed that Bhabha Atomic Research Centre (BARC), Mumbai, India topped the list with 153 authorships followed by Los Alamos National Laboratory, USA with 105 authorships.

2. OBJECTIVES

The main objective of the study was to present the mapping of various dimensions of Indian contributions in the field of thorium by way of analysing the following features of research output:

- To find country-wise distribution of research output
- To find year-wise growth of publications
- To find authorship and collaboration pattern in the publications
- To find the most prolific authors in the field
- To find the extent of international collaboration
- To find sector/institution-wise contributions
- To find highly productive Indian institutes
- To find subject category-wise contributions
- To find the channels of communications used by the scientists
- To find out language-wise distribution of publications, and
- To find out the high frequency keywords appeared in the indexer-assigned-descriptors (DEI) field in INIS

3. MATERIALS & METHODS

The data source for the study was International Nuclear Information System (INIS) on disc (CD-ROM), published by the INIS Central Secretariat at International Atomic Energy Agency HQrs at Vienna, Austria. It is the world's leading and the most comprehensive abstracting and indexing service that provides all aspects of peaceful applications of nuclear science and technology. Records pertaining to thorium research in India were downloaded for 1970-2004 using suitable search strategy (thorium in words anywhere and India in AU fields).

A total of 2399 records were downloaded. The bibliographic details for each record included author, author's affiliation, title, type of document, source of publication, year of publication, keywords, language of the article, country of publication, etc. All these bibliographic details were transferred to spread sheet application and the data was analysed as per objective of the study.

4. RESULTS & DISCUSSION

4.1 Country-wise Distribution of Output in Thorium Research

There were 132 participating members in International Nuclear Information System (INIS) as on 2004 including 113 countries and 19 international organisations actively engaged in research and development activities

in nuclear science and technology. However, some countries have been more active in the field of thorium research and have produced a total of 28, 694 publications during the period under study.

Figure 1 lists top 22 countries actively pursuing research in this field. USA topped the list with 8049 (28.05 per cent) publications followed by India with 2399 (8.36 per cent) publications, Germany with 2383 (8.30 per cent) publications, Japan with 1560 (5.44 per cent) publications, France with 1169 (4.07 per cent) publications, Peoples Republic of China with 965 (3.36 per cent) publications, and Brazil with 804 (2.80 per cent). USA is, thus, contributing more than 75 per cent of the total research output in thorium.

This shows that the institutions pursuing research in the field of thorium in these countries received major support from their respective governments.

4.2 Year-wise Growth of Publications in Thorium in terms of Publications published in India & Abroad

During 1970-2004, India has produced a total of 2399 publications in the field of thorium. The maximum publications (165) were published in 2000. The average number of publications per year was 68.54. The total and maximum publications published outside India during this period were 767 (31.98 per cent) and 37 in 1977, respectively.

Figure 2 gives year-wise growth of publications published in India and abroad in the field of thorium during 1970-2004 as per INIS database. There were only nine publications in 1970. Post 1970, there was a consistent growth in the number of publications except during 1983-1985. The period under study clearly indicates sustained growth of interest of Indian nuclear scientists in this field, and publication of more number of papers through Indian channels of communication.

4.3 Authorship & Collaboration Pattern

The year-wise authorship and collaboration pattern among Indian nuclear scientists in the field of thorium research is given in Fig. 3 and Table 1. Authorship trend is towards multi-authored papers as 85.70 per cent of the papers were multi-authored. Papers authored by two, three, four and five persons account for 26.09 per cent, 22.09 per cent, 15.38 per cent, and 11.09 per cent, respectively. Single-authored papers were 14.30 per cent.

Table 1 shows that there were 26 papers with more than 10 authors. During 1990-2004, the collaboration trend was more intensified with papers having as many as 23 collaborators. The highest collaboration

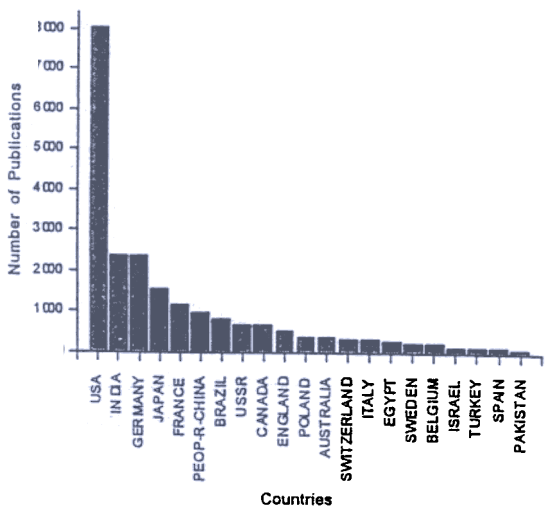

Figure 1. Country-wise distribution of thorium literature

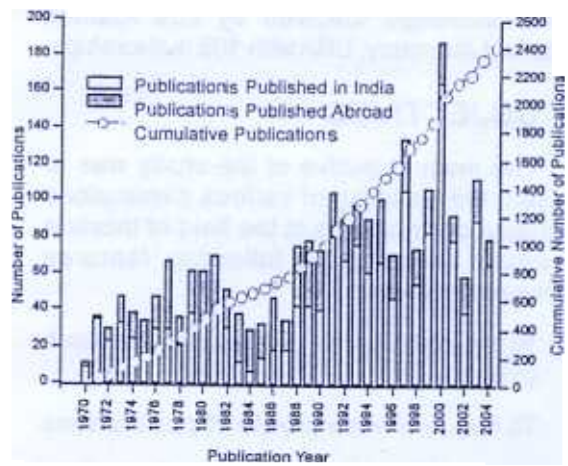

Figure 2. Year-wise growth of thorium research in terms of publications published in India and abroad

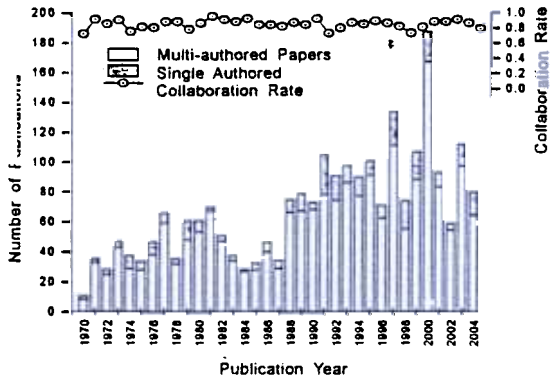

Figure 3. Year-wise authorship and collaboration pattern by Indian scientists

rate was found in 1981 (0.96) and 1984 (0.93).

4.4 Most Prolific Authors

In all, 3004 authors have contributed 2399 papers and produced 8014 authorships. The most prolific authors were: R.K. Choudhary, with 71 papers; A. Saxena with 61 papers; D.M. Nadkarni with 58 papers; S.S. Kapoor with 48 papers; D.C. Biswas with 46 papers, all at Nuclear Physics Division, BARC; S.B. Manohar Radiochemistry Division, B.K. Nayak, Nuclear Physics Division and V. Venugopal, Radiochemistry Division, all at BARC with 41 papers each; A. Ramanujam, Fuel Reprocessing Division, BARC with 38 papers; S. Kailas, Nuclear Physics Division, BARC with 37 papers; P.R.Vasudeva Rao, Fuel Chemistry Division, Indira Gandhi Centre for Atomic Research (IGCAR) with 36 papers; V.K. Manchanda, Radiochemistry Division, BARC, with 34 papers; A. Chatterjee, Nuclear Physics Division, BARC with 33 papers; A. Kakodkar, Reactor Engineering Division, BARC with 32 papers; H.S. Dang, Internal Dosimetry Division, BARC with 31 papers and T.V. Ramachandran, Environmental Assessment Division, BARC with 30 papers. Table 2 provides the names of most prolific authors who have contributed 20 or more papers.

4.5 International Collaboration in Authorship

In recent years, every country has realised the importance of scientific research for its growth, and started initiating programmes which enables scientists to have more interactions with other scientists, both at national and international levels. The study also measures the extent of international collaboration by the Indian scientists in the field of thorium. This trend may throw some light on the collaboration of scientific work among Indian and foreign institutions.

There were 79 international collaborative papers by 23 countries with 90 authorships. Bilateral collaborative papers accounted for 91.14 per cent. Table 3 gives the list of countries which collaborated with India. There were 85 international institutes who had collaborated with the indian institutes. Table 4 provides the list of international institutes who have collaborated with the indian institutes.

4.6 Sector/Institution-wise Contributions

Various Indian institutions contributing to the thorium literature have been grouped into two different sectors: (a) institutions under Department of Atomic Energy (DAE) and (b) non-DAE institutions. The analysis shows that DAE was by far the largest contributor accounting for nearly 1809 (64.63 per cent) authorships of the total output followed by non-DAE institutions with 990 (35.37 per cent) authorships. Figure 4 gives the sector-wise breakup of the contributors.

In all, 334 institutions have contributed 2799 authorships of which BARC topped the list with 1251 (44.69 per cent) followed by IGCAR, Kalpakkam with 168 (6.0 per cent), Atomic Minerals Division, Hyderabad with 71 (2.54 per cent), Utkal University, Bhubaneswar with 43 (1.54 per cent), Saha Institute of Nuclear Physics, Kolkata with 31(1.11 per cent), Punjabi University, Patiala with 30 (1.07 per cent) and Physical Research Laboratory, Ahmedabad with 28 (1.0 per cent) authorships.

Table 5 provides the names of the most productive Indian institutes in thorium research.

Table 1. **Authorships and collaboration trend in thorium research in India**

Year	Number of papers under various authorships																			Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20	22	23	
1970	3	7	1																		11
1971	3	18	6	5	2		1	1													36
1972	4	16	4	2	2			1													29
1973	4	21	8	6	3	1	2	1			1										47
1974	9	14	9	5	1																38
1975	6	15	7	6																	34
1976	9	18	11	6	1	2															47
1977	7	24	12	12	6	1			2			2									66
1978	4	14	9	3	4	1	1														36
1979	13	13	25	7	3																61
1980	8	23	16	7	5	1	1														61
1981	3	25	27	9	5			1													70
1982	4	19	11	9	5	1	2														51
1983	4	14	9	4	3	3	1														38
1984	2	9	12	3	1	1	1														29
1985	5	11	11	3	3																33
1986	7	13	11	9	3	3			1												47
1987	6	11	11	4	1	1	1														35
1988	9	27	17	10	7	3	2														75
1989	12	25	17	8	13	2	1						1								79
1990	5	25	12	10	11	2		3		3	1	1									73
1991	27	23	16	14	10	5	2	1	3	2	1						1				105
1992	17	23	21	14	5	7	1	1	2												91
1993	12	12	16	21	16	5	4	4	6			2									98
1994	13	18	23	14	9	7	3	2			1										90
1995	10	20	29	16	14	6	2	1	2						1						101
1996	9	14	11	11	12	7	2	2	3												71
1997	23	20	30	24	19	6	3	3		2	3								1		134
1998	19	9	11	11	20			1	1				1			1					74
1999	19	21	30	12	13	5	5		1		1										107
2000	21	36	33	36	25	20	10	2	2		2			1							188
2001	10	11	27	16	13	10	3	2										1			93
2002	5	19	5	18	5	3	1	2										1			59
2003	15	23	17	21	15	6	8	4	3												112
2004	16	15	15	13	11	4	2	1		1	1									1	80
Total	343	626	530	369	266	113	59	33	26	8	11	5	2	1	1	1	1	2	1	1	2399
%	14.30	26.09	22.09	15.38	11.09	4.71	2.46	1.38	1.08	0.33	0.46	0.21	0.08	0.04	0.04	0.04	0.04	0.08	0.04	0.04	100%

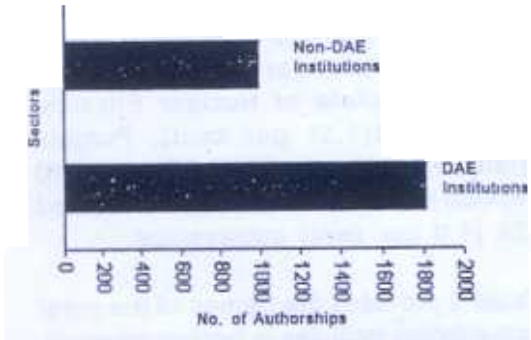

Figure 4. Sector-wise distribution of authorships

4.7 Subject Category-wise Contributions

The contents of INIS database are divided into 99 subject categories (S 1 to S 99). But the Indian contributions published on thorium during 1970-2004 were covered by only 23 subject categories.

The subject categories list given in Table 6 shows that maximum (622) publications were on inorganic, organic, physical and

Table 2. Most productive authors in thorium research in Indian institutes

Rank	Author	No. of papers	Division/Department	Institute	Period of productivity	TPY	APY
1	Choudhury, RK	71	Nuclear Physics Division	BARC	1989-2004	16	4.44
2	Saxena, A	61	Nuclear Physics Division	BARC	1989-2004	16	3.81
3	Nadkarni, DM	58	Nuclear Physics Division	BARC	1971-1999	29	2.00
4	Kapoor, SS	48	Nuclear Physics Division	BARC	1971-2004	34	1.41
5	Biswas, DC	46	Nuclear Physics Division	BARC	1990-2004	15	3.07
6	Manohar, SB	41	Radiochemistry Division	BARC	1981-2003	23	1.78
6	Nayak, BK	41	Nuclear Physics Division	BARC	1989-2002	14	2.93
6	Venugopal, V	41	Fuel Chemistry Division	BARC	1973-2004	32	1.28
7	Ramanujam, A	38	Fuel Reprocessing Division	BARC	1973-2003	31	1.23
8	Kailas, S	37	Nuclear Physics Division	BARC	1986-2004	19	1.95
9	Vasudeva Rao, PR	36	Fuel Chemistry Division	IGCAR	1988-2004	17	2.12
10	Manchanda, VK	34	Radiochemistry Division	BARC	1976-2004	29	1.17
11	Chatterjee, A	33	Nuclear Physics Division	BARC	1982-2004	23	1.43
12	Kakodkar, Anil	32	Reactor Engineering Division	BARC	1991-2004	14	2.29
13	Dang, HS	31	Internal Dosimetry Division	BARC	1985-2001	17	1.82
14	Ramachandran, TV	30	Environmental Assessment Division	BARC	1979-2001	23	1.30
15	Paul, AC	28	Health Physics Division	BARC	1979-2003	25	1.12
16	Pillai, PMB	27	Health Physics Division	BARC	1981-2004	24	1.13
16	Nambi, KSV	27	Health Physics Division	BARC	1971-2000	30	0.90
17	Jaiswal, DD	26	Health Physics Division	BARC	1985-2002	18	1.44
18	Srinivasan, TG	25	Fuel Chemistry Division	IGCAR	1989-2004	16	1.56
18	Das, KC	25	Department of Chemistry	Utkal University	1977-1996	20	1.25
18	Reddy, AVR	25	Radiochemistry Division	BARC	1981-2003	23	1.09
19	Patil, SK	24	Fuel Chemistry Division	BARC	1973-1996	24	1.00
19	Sastry, MD	24	Radiochemistry Division	BARC	1982-2001	20	1.20
19	Sunta, CM	24	Atomic Energy Regulatory Board	BARC	1971-1995	25	0.96
20	Ganguly, C	23	Radio Metallurgy Division	NFC	1985-2004	20	1.15
20	Siddappa, K	23	Department of Physics	Mangalore University	1989-2004	16	1.44
21	Aggarwal, SK	22	Fuel Chemistry Division	BARC	1989-2004	16	1.38
21	Chakravortty, V	22	Department of Chemistry	Utkal University	1979-2003	25	0.88
21	Mishra, UC	22	Health Physics Division	BARC	1971-2000	30	0.73
21	Sood, DD	22	Radiochemistry and Isotope Group	BARC	1971-1999	29	0.76
21	Tomar, BS	22	Radiochemistry Division	BARC	1990-2004	15	1.47
22	Shukla, VK	21	Environmental Assessment Division	BARC	1971-2003	33	0.64
22	Allawadhi, KL	21	Department of Physics	Punjabi University	1981-1999	19	1.11
22	Khan, AH	21	Health Physics Division	BARC	1975-2004	30	0.70
22	Sood, BS	21	Department of Physics	Punjabi University	1972-1996	25	0.84
22	Ramakrishna, VV	21	Radiochemistry Division	BARC	1973-2004	32	0.66
23	Pillai, KC	20	Health Physics Division	BARC	1979-1994	16	1.25
23	Prasad, R	20	Radiochemistry Division	BARC	1971-2004	34	0.59
23	Ramaniah, MV	20	Radiochemistry Division	BARC	1971-1989	19	1.05

(TPY= total productive years; APY= average number of papers per year)

Table 3. International collaboration in thorium research

Sl. No.	Country	Authorships
	USA	
	UK	
	Italy	
	Germany	
	Germany, FR	
	Japan	
	Russian Federation	
8	Switzerland	
9	Australia	
10	France	
11	USSR	
12	Austria	
13	Netherlands	
14	Belgium	
15	Canada	
16	China	
17	Korea, Republic of	1
18	Monaco	1
19	New Zealand	1
20	Poland	1
21	Portugal	1
22	Taiwan	1
23	Ukraine	1
1-23	Total	90

analytical chemistry (S 37) followed by 294 publications on environmental sciences (S 54), 290 publications on nuclear physics and radiation physics (S 73) and 279 publications on radiation chemistry, radiochemistry and nuclear chemistry (S 38).

4.8 Preference of Channels of Communications by the Indian Scientists

Indian scientists communicated their research results through a variety of communication channels. Figure 5 depicts that 47.81 per cent of the literature was published in journals followed by 40.60 per cent in conference literature, 10.46 per cent in reports and 1.13 per cent in books.

4.9 Preference of Journals for Communication by the Scientists

The distribution of papers were spread over 215 journals. The leading Indian journals preferred by the scientists were the *Journal*

Table 4. International institutes with Indian collaboration in thorium research

Sl. No.	International Institutes	Authorship
2.		4
3.		3
4.		3
5.		3
6		3
7.		3
8.		2
9.		2
10.		2
11.		2
12.		
13.		2
14.		2
15.		2
16		2
17.		2
18.		2
19.		2
20.		2
21.		2
22.		2
23.		2
25-85.		62
1-85.		118

of the Indian Chemical Society with 78 papers, followed by *Indian Journal of Chemistry A* with 60 papers, *Bulletin of Radiation Protection* with 56 papers, *Journal of Radioanalytical and Nuclear Chemistry* with 54 papers, *Radiation*

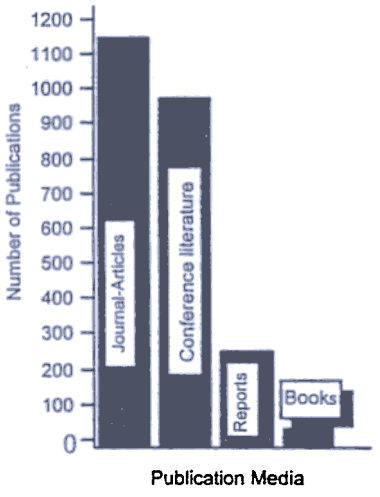

Figure 5. Publication media-wise distribution of publications preferred by the scientists

Protection and Environment with 37 papers, *Exploration and Research for Atomic Minerals*, and *Journal of Geological Society of India* with 35 papers each. Table 7 provides journal-wise scattering of publications. More than 50 per cent of the publications were published in the journals with impact factors ranging from 0.0 to 0.49 and rest were published in the journals having impact factors ranging from 0.50 to 30.99. The distribution of journals as per impact factors is given in Fig. 6.

4.10 Country-wise Distribution of Journals

The publications have been spread over 215 journals published in 15 countries.

Table 6. Subject category-wise distribution of thorium research in India

Rank	Subject categories	No. of papers	Percentage
1	Inorganic, organic, physical and analytical chemistry (S 37)	622	25.93
2	Environmental sciences (S 54)	294	12.26
3	Nuclear physics and radiation physics (S 73)	290	12.09
4	Radiation chemistry, radiochemistry and nuclear chemistry (S 38)	279	11.63
5	Nuclear fuel cycle and fuel materials (S 11)	217	9.05
6	Specific nuclear reactors and associated plants (S 21)	154	6.42
7	Materials science (S 36)	142	5.92
8	Radiation protection and dosimetry (S 61)	96	4.00
9	Classical and quantum mechanics, general physics (S 71)	72	3.00
10	Radiation, thermal, and other environmental pollutant effects on living organisms and biological materials (S 63)	43	1.79
11	General studies of nuclear reactors (S 22)	40	1.67
12	Instrumentation related to nuclear science and technology (S 46)	37	1.54
13	Management of radioactive wastes, and non-radioactive wastes from nuclear facilities (S 12)	23	0.96
14	Energy planning, policy and economy (S 29)	21	0.88
15	Plasma physics and fusion technology (S 70)	14	0.58
16	General and miscellaneous (S 99)	10	0.42
17	Atomic and molecular physics (S 74)	9	0.38
18	Particle accelerators (S 43)	8	0.33
19	Condensed matter physics, superconductivity and super fluidity (S 75)	7	0.29
20	Isotopes and radiation sources (S 07)	6	0.25
20	Applied life sciences (S 60)	6	0.25
21	Geosciences (S 58)	5	0.21
22	Engineering (S 42)	4	0.17
	Total	2399	100

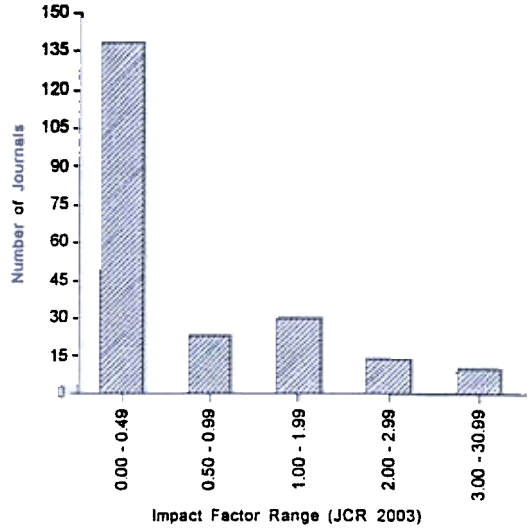

Figure 6. Distribution of journals as per impact factor

Figure 7 gives the country-wise distribution of journals publishing Indian literature on thorium. The largest numbers of journals are from India with 591 (51.53 per cent) publications in 81 journals, followed by UK 155 (13.51 per cent) publications in 42 journals, Switzerland with 108 (9.42 per cent) publications in 9 journals and USA with 103 (4.48 per cent) publications in 23 journals.

4.11 Preference of Conferences for Communication by the Scientists

Conference literature is one of the most preferred channels of communications for scientists and engineers, especially in the fields like nuclear science and technology and space research, for dissemination of nascent information. Figure 8 gives the year-wise growth of conference literature where Indian publications related to thorium are published.

More than 40 per cent of the literature on thorium is published in conference proceedings indicating the importance of the conference literature for the scientists as the second most preferred channel of communication. The highest (151) publications were published in 2000. The most popular conferences which published literature on thorium are given in Table 8.

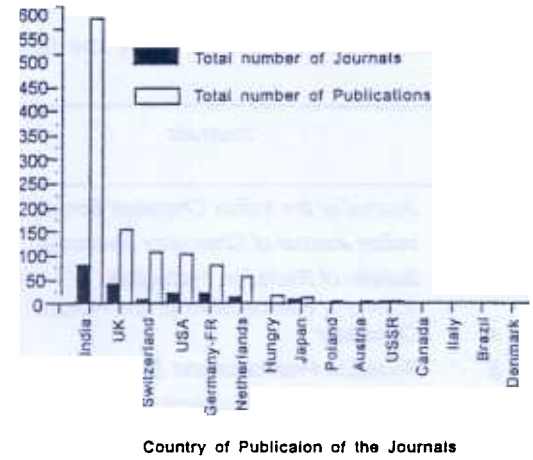

Figure 7. Country-wise distribution of journals preferred for publication by the scientists

4.12 Language-wise Distribution of Publications

Indian scientists have contributed more predominantly in English than in any other language as 99.5 per cent of the Indian contributions were in English. The contributions in other languages (Russian, German, Japanese and Hindi) were about 0.5 per cent.

4.13 Distribution of Keywords

Keywords are one of the best scientometric indicators to understand and grasp instantaneously the thought content of the papers and to find out the growth of the subject field. Analysis of the keywords appeared either in the title or assigned by the indexer or the author himself, helps in knowing in which direction the knowledge

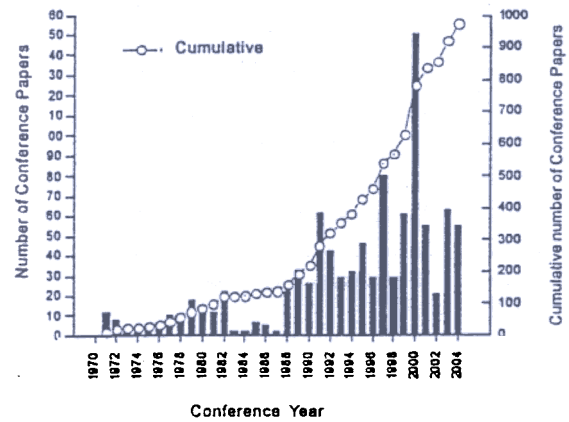

Figure 8. Year-wise growth of conference literature

Table 7. Journals preferred by the Indian scientists for publishing articles on thorium

Sl. No.	Journals	Country	No. of publications	IF 2003	Period of publication	TY
	Journal of the Indian Chemical Society	India	78	0.275	1971-2003	33
2	*Indian Journal of Chemistry Section A*	India	60	0.489	1976-2002	27
3	*Bulletin of Radiation Protection*	India	56	-	1978-1999	22
4	*Journal of Radioanalytical and Nuclear Chemistry*	Switzerland	54	0.472	1984-2004	21
5	*Radiation Protection and Environment*	India	37	-	1997-2003	7
6	*Exploration and Research for Atomic Minerals*	India	35	-	1992-1999	8
7	*Journal of the Geological Society of India*	India	35	0.299	1971-2004	34
8	*Current Science*	India	33	0.694	1971-2004	34
9	*Journal of Inorganic and Nuclear Chemistry*	UK	27	-	1972-1981	10
10	*Journal of Radioanalytical and Nuclear Chemistry Articles*	Switzerland	27	-	1985-1992	8
	Asian Journal of Chemistry	India	26	0.211	1992-2003	12
12	*Physical Review C*	USA	26	2.708	1974-2004	31
13	*Radiochimica Acta*	Germany-FR	24	0.94	1970-2004	35
14	*Pramana*	India	19	0.333	1977-2003	27
15	*Journal of Nuclear Materials*	Netherlands	17	1.179	1977-1999	23
16	*Talanta*	UK	16	2.091	1972-1993	22
17	*Indian Journal of Pure and Applied Physics*	India	15	0.366	1972-2001	30
18	*Journal of Physics B*	UK	13	1.724	1979-2001	23
19	*Indian Journal of Environmental Protection*	India	11	-	1989-2002	14
20	*Journal of Radioanalytical and Nuclear Chemistry Letters*	Switzerland	11	-	1984-1991	8
21	*Separation Science and Technology*	USA	11	0.89	1979-1998	20
22	*Transactions of the Indian Ceramic Society*	India	11	-	1971-2004	34
23	*Analyst*	UK	10	2.251	1983-1995	13
24	*Analytical Letters*	USA	10	0.929	1979-1990	12
25	*Bulletin of Materials Science*	India	10	0.529	1980-2003	24
26	*Zeitschrift fuer Physik A*	Germany-FR	10	-	1981-1997	17
27	*Nuclear Geophysics*	UK	9			
28-32	5 journals with 8 papers each	-	40			
33-38	6 journals with 7 papers each		42			
39-42	4 journals with 6 papers each		24			
43-56	14 journals with 5 papers each		70			
57-70	14 journals with 4 papers each		56			
71-93	23 journals with 3 papers each		69			
94-126	33 journals with 2 papers each		66			
127-215	89 journals with 1 paper each		89			
1-215	Total		1147			

(IF = Impact factor; TY = Total year)

Table 8. Most popular conferences which covered articles on thorium research in India

Rank	Conference name	No. of papers	Year	Place of conference
	INSAC-2000: 11th Annual Conference of Indian Nuclear Society on Power from Thorium Status, Strategies and Directions	100	2000	Mumbai
2	NUCAR 2003: 6th National Symposium on Nuclear and Radiochemistry	32	2003	Mumbai
3	NUCAR 2001: 5th National Symposium on Nuclear and Radiochemistry	29	2001	Pune
	Indo-Japan Seminar on Thorium Utilization	24	1991	Mumbai
4	INSAT-97: 12th ISAS National Symposium on Analytical Techniques for Safety and Sufficiency of Natural Resources/Products	24	1997	Kottayam
4	Nuclear and Radiochemistry Symposium	24	1992	Visakhapatnam
5	NUCAR 99: Nuclear and Radiochemistry Symposium	20	1999	Mumbai
6	NUCAR 97: Nuclear and Radiochemistry Symposium	19	1997	Kolkata
6	NUCAR-95: Nuclear and Radiochemistry Symposium	19	1995	Kalpakkam
7	SLA-99: DAE-BRNS Symposium on Spectroscopy of Lanthanides and Actinides	16	1999	Mumbai
	Symposium on Radiochemistry and Radiation Chemistry	16	1989	Kalpakkam
8	DAE-BRNS, Mumbai (India)	15	1995	Mumbai
8	Radiochemistry and Radiation Chemistry Symposium	15	1982	Pune
8	Symposium on Radiochemistry and Radiation Chemistry	15	1990	Nagpur
9	ISMAS-SJS-2003: 9th ISMAS Silver Jubilee Symposium on Mass Spectrometry	13	2003	Dona Paula
10	DAE Symposium on Nuclear Physics	12	1991	Mumbai
11	3rd National Symposium on Environment with Special Emphasis on High Background Radiation Areas	11	1994	Thiruvananthapuram
11	DAE Symposium on Nuclear Physics	11	1992	Mumbai
11	Emerging Trends in Separation Science and Technology.	11	2004	Mumbai
11	THERMANS 2004: 14th National Symposium on Thermal Analysis	11	2004	Baroda
12	CQCNF-2002:Ccharacterisation and Quality Control of Nuclear Fuels	10	2004	Hyderabad
12	INSAC-2001: 12th Annual Conference of Indian Nuclear Society	10	2001	Indore
12	International Symposium on Nuclear Physics	10	2000	Mumbai
12	NSE-13: 13th National Symposium on Environment	10	2004	Shillong
12	Radiochemistry and Radiation Chemistry Symposium	10	1988	Mumbai
13	DAE Symposium on Nuclear Physics	9	1997	Bangalore
13	DAE Symposium on Nuclear Physics	9	1993	Calicut
14	DAE Symposium on Nuclear Physics	8	1996	Pantnagar
14	INSAC-2003: 14th Annual Conference of Indian Nuclear Society;1st BRNS Conference on Nuclear Fuel Cycle Kalpakkam	8	2003	Kalpakkam
14	SSNTD-98: 11th National Symposium on Solid State Nuclear Track Detectors and Applications	8	2000	Amritsar
14	THERMANS 2000: 12th National Symposium on Thermal Analysis	8	2000	Gorakhpur
15	9 Conferences with 7 papers each	63		
16	5 Conferences with 6 papers each	30		
17	9 Conferences with 5 papers each	45		
18	12 Conferences with 4 papers each	48		
19	21 Conferences with 3 papers each	63		
20	41 Conferences with 2 papers each	82		
21	106 Conferences with 1 paper each	106		
1-21	Total	974		

grows. The high frequency keywords enable us to understand the aspects of thorium under study. The keywords appeared in the DEI field in INIS were analysed for the purpose. The high frequency keywords were: thorium (559), uranium (316), thorium oxides (269), India (257), solvent extraction (236), quantitative chemical analysis (221), and thorium 232 (202).

Table 9 gives a list of high frequency keywords which appeared more than 50 times.

5. CONCLUSION

The study is concerned about the scientometric dimensions of thorium research in India as reflected in INIS database during 1970-2004. Although the concept of utilisation of thorium in reactors for generation of electricity was conceived as far back as 1958 by Homi Jehangir Bhabha, the research on design and development activities started much later. Research on thorium in India started with a modest beginning of nine publications in 1970. A consistent growth of publications was observed thereafter with a marginal

Table 9. Keywords with ≥ 50 frequencies appeared in the thorium research publications in the DEI field

Keywords	Frequency	Keywords	Frequency
Thorium		Fission fragments	
Uranium		Potassium 40	
Thorium oxides		Uranium oxides	
India		Spectrophotometry	
Solvent extraction		Radiation monitoring	
Quantitative chemical analysis		Ion exchange	
Thorium 232		Flowsheets	
Chemical composition		Nuclear fuels	
pH value		Dose rates	
Uranium 233		Thermal gravimetric analysis	
Monazites		Thorium nitrates	
Experimental data		Reprocessing	70
Chemical preparation		Thorium 232 target	70
Trace amounts		Radioactivity	69
Infrared spectra		Aqueous solutions	68
Fission		Sensitivity	68
Uranium 238		Uranium dioxide	66
Gamma radiation		Mixed oxide fuels	65
Ligands		Quantity ratio	65
Chemical reaction kinetics		Radionuclide migration	64
Radiation doses		Background radiation	63
Cross sections		Fuel pellets	63
Distribution functions		Electric conductivity	61
Nitric acid		Radium 226	61
Structural chemical analysis		EDTA	60
TBP		PHWR type reactors	60
Gamma spectroscopy		Carbon 12 reactions	57
Interfering elements		HWLWR type reactors	57
Temperature dependence		Radiation protection	57
Thorium complexes		Isotope ratio	54
Angular distribution		Zirconium	54
Thorium cycle		Neutron activation analysis	53
Natural radioactivity		Plutonium oxides	53
MEV range 10100		Comparative evaluations	52
Stability		Impurities	52
Environment		Leaching	51
Plutonium		Oxygen 16 reactions	50
X-ray diffraction		Potentiometry	50

decrease during 1983-1985. USA is the top player in this field with 8049 (28.05 per cent) publications. India ranked second among other countries with 2399 (8.30 per cent) publications. The average publications per year were 68.54.

There are many academic and research and development institutions involved in research on thorium in addition to DAE institutions. However, DAE institutions topped the list with 1809 (64.63 per cent) authorships followed by academic institutions with 718 (25.65 per cent) authorships and non-DAE institutions with 264 (9.43 per cent) authorships. BARC, Mumbai ranked first with 1251 authorships followed by IGCAR, Kalpakkam with 168 authorships. Collaboration trend was towards multi-authored papers as 85.70 per cent of the papers were collaborative, which indicates the multidisciplinary nature of research requiring highly skilled researchers from many disciplines. Bilateral international collaboration accounted for 90.14 per cent of the total collaborative papers.

Indian scientists preferred to publish their publications in journals (47.81 per cent) as well as in conference literature (40.60 per cent).

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